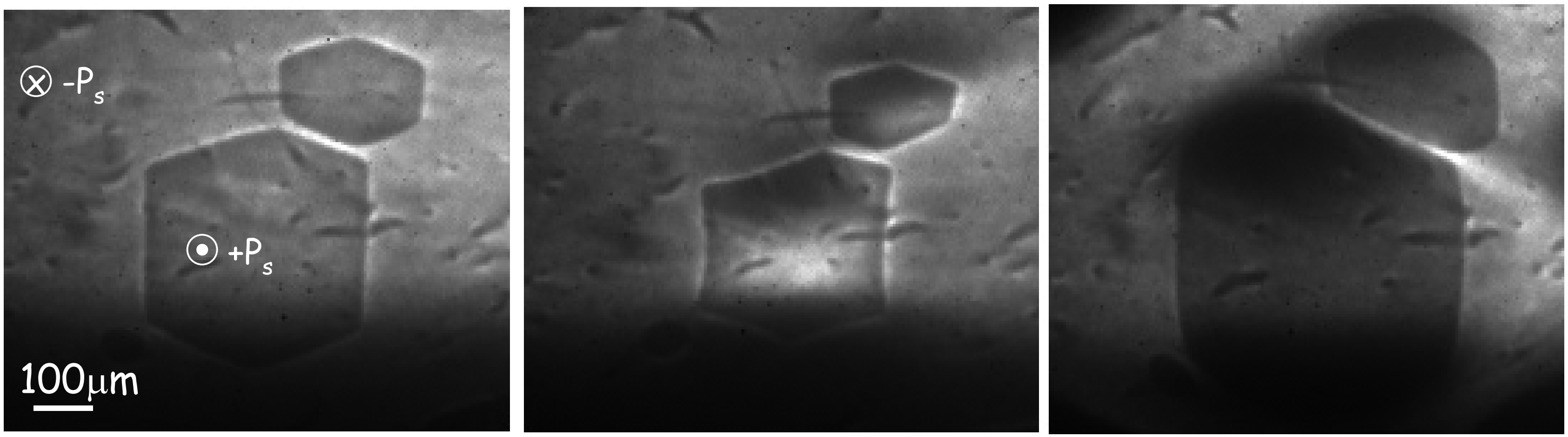
Ferroelectric Domains for Tunable Optics

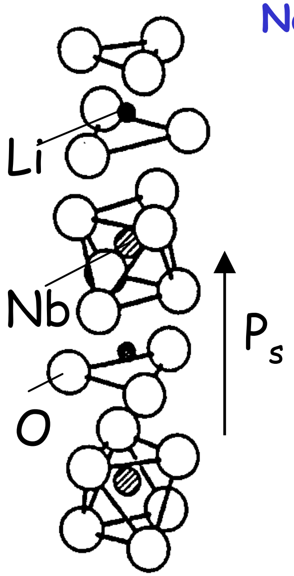
Synchrotron Xray (00.12) diffraction image from ferroelectric $LiNbO_3$ domains



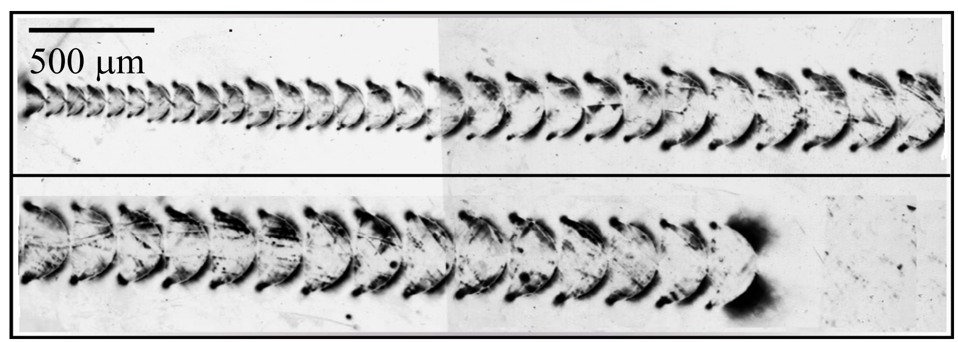
No field

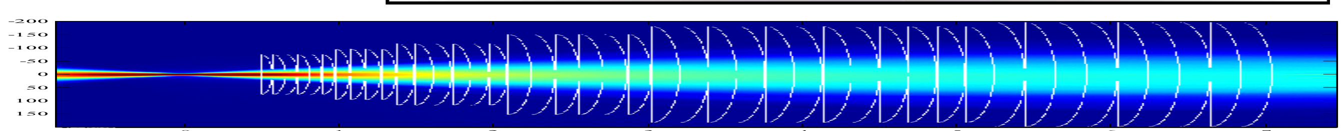
Focusing Xray under +9V/µm

Defocusing Xray under -9V/µm



Electro-optic Domain Lens Stack in $LiNbO_3$ That can dynamically focus visible light using External Electric field.





Materials Science/Real-time Studies of Domain Dynamics in Ferroelectrics for Photonics-9984691 (NSF-CAREER). [Ferroelectric materials possess a built-in electrical dipole moment, P_s, that can be reoriented by an external electric field (schematic, bottom left). Regions of uniform dipole moment are called *domains*. The transition between two domains is called a *domain wall*.] In-situ X-ray imaging of ferroelectric domain wall strains under an external field reveal fascinating effects, such as long range strains extending over 100 μm and a *focusing and defocusing* of the X-ray beam by the hexagonal domains (top series of images). However, at this field, the original domain walls were confirmed, in reality, to *not move at all!* A detailed computer simulation of the X-ray focusing effect based on diffraction theory reveals that the lattice planes (00.12) warp differently inside and outside a domain under an applied electric field due to the piezoelectric effect. When the polarity of the field is switched, the domain region switches from being a concave mirror (image 2, top) to a convex mirror (image 3, top), respectively focusing and defocusing the X-ray beam and thus distorting the Bragg image. The strain regions near domain walls extend over hundreds of micrometers, which we have shown to have fundamental consequences: for example, the intrinsic coercive fields required to move domain walls in ferroelectrics would drop by an order of magnitude if a domain wall broadens locally, as seen here.[*Appl. Phys. Lett,* **80**, 2740 (2002)]

This work has interesting technological implications. *Tunable X-ray lenses*, which are normally difficult to make, can be fashioned from microengineered ferroelectric domains. Ferroelectric domains can also be shaped as *Electro-optical lenses* (lower right in grey), which can dynamically focus and defocus visible and infrared light under an external field (simulation, bottom in color). The X-ray work has been presented in three conference talks, and is in submission process for *Phys. Rev. Lett*. The electro-optic lens work is published in *Appl. Opt*. **31**, 5638 (2001).

Diversity and International Cooperation at the Frontier of Materials for Photonics
Prof. V. Gopalan's research group at Penn State (DMR-9984691) is engaged in fundamental studies of ferroelectrics as a class of materials towards developing them as a single platform for integrated optical devices. The NSF supported personnel from diverse backgrounds are: *Vincent Mitchell*, Undergraduate summer intern (2002) (Electrical Engineering), University of New Orleans, African American; *Estefania Pickens*, Undergraduate summer intern (2001), Woman, Hispanic; *Sungwon Kim*, Graduate student, Materials Science and Engineering, (MSE), Korean; *David A. Scrymgeour*, NSF Graduate Fellow awardee, (MSE), American; *Lili Tien*, Graduate Student, (MSE), Woman, China; *Cheng-Nan Lin*, Graduate Student (MSE), Taiwan; *Natalia Malkova*, theoretical physicist from Moldova, supported by NSF MRSEC on correlated phenomena in confined geometries, woman;

Awards
Robert R. Coble Award
Awarded to V. Gopalan, by the American Ceramic Society for Young Scholars, (*April* 2002)

NSF Graduate Fellowship
Awarded to my student, David A. Scrymgeour, National Science Foundation (2001)

Alumni Dissertation Award
Awarded to my student, Sungwon Kim, Pennsylvania State University (2002).

Venkatraman Gopalan/Penn State; DMR-9984691

On Nov 3 and Dec 2, 2002, Douglass Science Academy for Girls conducted a workshop for *fifty* bright 9th and 10th grade girls from New Jersey high schools, titled, "A Microscopic Look into the Materials World." As part of this event, held at Rutgers University, V. Gopalan, from Penn State conducted a workshop called the "*The Science and Technology of Light*." This workshop consisted of 10 sessions (45 minutes per session) of hands-on experiments and discussions with groups of 5 girls at a time, centering on the information superhighway, the internet, the nature of light, how it is different from sounds, why it is so important for today's high-speed optical communications, and how one can trap, transmit and code information with light through optical fibers, lasers and LEDs. We assembled (see below) an *optical voice link* using a simple microphone, speaker, simple circuit and an optical fiber. A person speaking through the microphone could be heard at the receiver after voice signals travel through an optical fiber! We also measured the speed of light by measuring the time it took light to travel 20 meters of optical fiber. We also played with, and talked about different colored LEDs and made Christmas lights. In all, it was a lot of fun!